IV.2 Solid Oxide Fuel Cell Coal-Based Power Systems

Objectives

- Develop and optimize a design of an integrated gasification fuel cell (IGFC) power plant incorporating a solid oxide fuel cell (SOFC)/gas turbine (GT) hybrid system that will produce highly efficient, environmentally benign and cost-effective electrical power from coal.
- Define and design a proof-of-concept system (POC) derived from the IGFC design and demonstrate operation with required performance characteristics.
- Resolve identified barrier issues concerning the SOFC and develop and demonstrate a SOFC building block for multi-MW system applications.

The project consists of three phases. Phase I of the project focuses on designing and estimating the cost of the IGFC system as well as the proof-of-concept system and resolving barrier issues relating to the SOFC, culminating in the demonstration of a fuel cell stack having the features suitable for use in a building block stack for multi-MW applications. Phase II involves optimizing and finalizing the IGFC and proof-of-concept designs and costs and testing a fuel cell module under hybrid conditions as a demonstration of the building block stack for the IGFC. Phase III aims at field-testing of a proof-of-concept system for extended periods to validate integration and demonstrate required performance characteristics.

Approach

Phase I

- Establish a baseline design of an IGFC system.
- Define a POC system.
- Identify the requirements of the systems, develop suitable system design, model and analyze the systems to evaluate performance and compare system performance with requirements for gap closure and system optimization.
- Conduct a cost estimate study to assess system costs.
- Evaluate a suitable stack design for operation under hybridized coal gas conditions using the Solid State Energy Conversion Alliance (SECA) technology as the baseline.
- Address critical technological issues concerning SOFC fabrication/manufacturing, scaleup, hybridized coal gas operation, and life/degradation.
- Build and test a stack having the features suitable for incorporation into a SOFC/GT system for IGFC applications.

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Accomplishments

Phase I of the project was initiated in October 2005, and the key accomplishments achieved to date are summarized below.

- Sixteen system design options for an IGFC plant were identified and evaluated. Two concepts were selected as the main go-forward options, with two other identified as viable risk-mitigation approaches.
- Initial IGFC analyses indicate that 50% higher heating value (HHV) efficiency with 90% CO_2 isolation is achievable.
- Product requirements for an IGFC plant were defined based on market data and DOE requirements.
- Key parameters that determine sintering behavior of large cells were identified.

Future Directions

Continue activities defined in the Phase I project plan, including:

- Develop and evaluate IGFC and POC system design concepts.
- Develop methodologies and models and conduct cost estimate of baseline IGFC system.
- Fabricate large-area cells. Modify and optimize fabrication process parameters for producing large-area cells.
- Measure SOFC performance maps over pressure and fuel composition ranges of interest.
- Establish baseline SOFC degradation rate in coal-based hybrid conditions and develop mitigation plan.
- Build and operate stacks incorporating large-area cells with simulated coal gas.

Introduction

This project aims at developing a highly efficient, environmentally benign, and cost-effective multi-MW solid oxide fuel cell (SOFC) based power system operating on coal. The project will be a critical step towards the overall goal of realizing large (>100 MW) fuel cell power systems that will produce electrical power at greater than 50% overall efficiency (HHV) from coal to AC power, including CO_2 separation preparatory to sequestration. The overall approach for this project is to integrate the SOFC with a gas turbine (GT) in a SOFC/GT hybrid power island. This power island is the primary power generation section of an overall IGFC coal-based power plant. This hybridization approach will provide a step-change improvement in performance over today's technology and a system efficiency greater than that achievable by either a simple cycle SOFC IGFC or an integrated gasification combined cycle (IGCC). The project consists of three phases and the key features of each of the phase are summarized in Figure 1.

Approach

The project is structured around three phases to address the system design of a cost-effective >100 MW IGFC system; advancement of SOFC fuel cell technology needed to meet the system requirements; validation of the technology through early component tests; and a proof-of-concept (POC) demonstration testing.

The focus of Phase I of the project is to develop the design of an IGFC power plant based on SOFC/GT hybrids and a proof-of-concept of that system, to resolve critical technological issues of the SOFC, and to demonstrate a fuel cell stack having the features required for multi-MW IGFC applications. To support this objective, the Phase I work concentrates on two main areas: system/product development and stack technology development.

- **System design development.** This work aims to establish a baseline design of an IGFC system and to define a proof-of-concept system. The effort will focus on identifying the requirements for the systems, developing suitable system designs, modeling and analyzing the systems to evaluate performance, and comparing system performance with requirements for gap closure and system optimization. A cost estimate study will be conducted to assess system costs.
- **Stack technology development.** This work aims to develop a high-performance, low-cost SOFC stack suitable for hybridization with a GT for multi-MW IGFC systems. The effort will involve evaluating a suitable design for the stack under hybridized coal gas conditions and addressing critical technological issues concerning fabrication/manufacturing scale-up, hybridized coal gas operation, and life/degradation. A stack having the features suitable for incorporation into a SOFC/GT system for IGFC applications will be fabricated and tested.

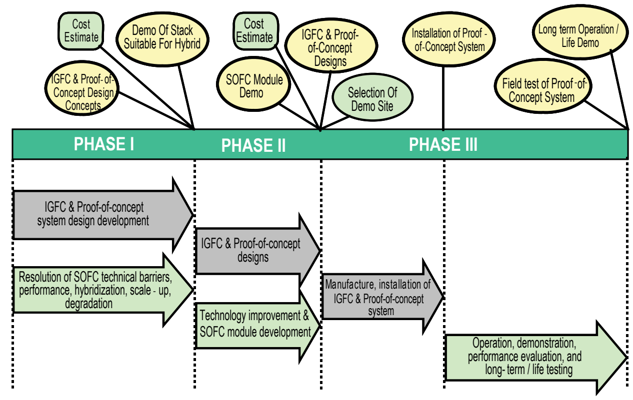

FIGURE 1. Overall Project Summary

Results

System Design Development

A survey of IGFC systems reported in the literature was conducted to establish the background for developing potential conceptual designs in this project. From the survey and brainstorming sessions, sixteen system design options for an IGFC plant were identified. In order to evaluate the system efficiency and CO_2 isolation performance potential of the concepts, simplified ASPEN models were created for several concepts. These models did not encompass the gasification system but used it as an interface (i.e., syngas and steam flows); therefore, certain assumptions had to be made. The results of the models indicate that 50% HHV efficiency with 90% CO_2 isolation is achievable for several IGFC designs. Based on these preliminary results, two concepts were selected as the main go-forward options, with two others identified as viable risk-mitigation approaches. The requirements for the IGFC conceptual system design have been established:

- 600 MW net power
- 50% HHV efficiency
- 90% CO_2 isolation
- < $400/kW for power producing blocks
- Bituminous coal, 10% moisture

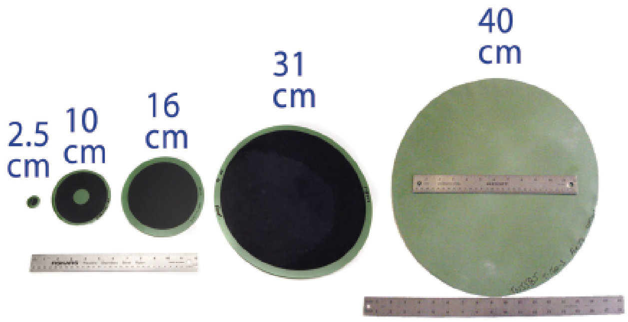

FIGURE 2. Large-Area SOFCs

Stack Technology Development

The tape calendering process has been used to fabricate SOFC cells. Using this process, cells sizes up to 40 cm have been successfully demonstrated (Figure 2). In terms of scale-up, a critical issue in manufacturing large-area cells by tape calendering is controlling the failure rate (yield) during the critical firing step. During the firing step, as the tape changes from the plastic to the brittle state, the probability of failure increases with increase in cell size. During firing, major causes for cell cracking include thermal gradients and stresses in the sintering tape; frictional forces between the sintering tape and non-sintering setter plate; and changes in the strength of the tape as a function of temperature. An improved understanding of the influence of these parameters is very important for process design and optimization for successful large-area cell fabrication. A list of key factors affecting the firing behavior of tapes has been compiled. Several parameters were subsequently identified based on ease of experimentation, and a screening design of experiments to understand the influence of these factors on firing yield was developed.

Conclusions and Future Directions

In the system development area, IGFC system concepts have been identified that are capable of meeting the DOE requirements of 50% HHV efficiency and 90% CO_2 isolation. These concepts are similar in nature to previously evaluated IGFC designs. Near-term system work focuses on developing detailed conceptual designs of the IGFC system and conducting preliminary system cost estimates.

In the stack development area, key factors affecting cell manufacturing scale-up by tape calendaring were identified, and a screening design of experiments was initiated. Near-term SOFC stack work focuses on developing a suitable stack design for IGFC system applications, optimizing the tape calendering process for manufacturing large-area cells, making cells and stacks and testing performance and degradation in pressurized coal-gas conditions.